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**NASA COMMUNICATIONS DIVISION (NASCOM)
TRACKING DATA RELAY SATELLITE SYSTEM
(TDRSS) SHUTTLE MULTIPLEXER-DEMULTIPLEXER
DATA SYSTEMS (MDM) AND SUPPORTING
ITEMS**

(NASA-CR-166817) NASA COMMUNICATIONS
DIVISION (NASCOM) TRACKING AND DATA RELAY
SATELLITE SYSTEM (TDRSS) SHUTTLE
MULTIPLEXER-DEMULTIPLEXER DATA SYSTEM (MDM)
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**S. R. New
Ford Aerospace & Communications Corporation
Space Information Systems Operation
1002 Gemini Avenue
Houston, Texas 77058**

**10 June 1981
Final Progress Report**

Prepared for:

**GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771**



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16. Abstract This document is the Final Progress Report required under NAS 5-25093. The MDM project included the design, documentation, manufacture, and testing of three MDM Data Systems for use at Goddard Space Flight Center (GSFC), Tracking and Data Relay Satellite System (TDRSS) Ground Station, and Johnson Space Center (JSC). The equipment is contained in 59 racks, and includes more than 3,000 circuit boards and 600 microprocessors. Spares, circuit card testers, a master set of programmable integrated circuits, and a program development system were included as deliverables.			
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PREFACE

This document is the Final Progress Report for Contract NAS 5-25093. The contract covered the development of the MDM Data Systems required by NASA during the TDRSS era of the Space Shuttle program. This report includes an Introduction, Progress and Problems Analysis, Schedule Conformance, New Technology, Items Awaiting Government Approval, and Project Conclusions in sections 1 through 6, respectively. The appendix is a summary of the contract history.

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ACRONYM LIST

AT	Acceptance Test
ATP	Acceptance Test Procedure
CDR	Critical Design Review
ECP	Engineering Change Proposal
EMC	Electromagnetic Compatibility
EQT	Equipment Qualification Test
EQTP	Equipment Qualification Test Procedure
FACC	Ford Aerospace & Communications Corporation
GFE	Government Furnished Equipment
GSFC	Goddard Space Flight Center
IDR	Interim Design Review
ITU	Input Terminal Unit
JSC	Johnson Space Center
MDM	Multiplexer-Demultiplexer
MHz	Megahertz
MTBF	Mean-Time-Between Failures
NASCOM	NASA Communications Division
NASA	National Aeronautics and Space Administration
O&M	Operations and Maintenance
OTU	Output Terminal Unit
PCB	Printed Circuit Board
PDR	Preliminary Design Review
PWB	Printed Wiring Board
QA	Quality Assurance
SISO	Space Information Systems Operation
TDRSS	Tracking and Data Relay Satellite System
TMR	Triple Modular Redundant

SECTION I

INTRODUCTION

This document is the Final Progress Report required under NAS 5-25093. Additional related tasks may be added to the basic multiplexer-demultiplexer (MDM) contract (NAS 5-25093), but all progress reporting for these additions will be in letter format.

The MDM project included the design, documentation, manufacture, and testing of three MDM Data Systems for use at Goddard Space Flight Center (GSFC), Tracking and Data Relay Satellite System (TDRSS) Ground Station, and Johnson Space Center (JSC). The equipment is contained in 59 racks, and includes more than 3,000 circuit boards and 600 microprocessors. Spares, circuit card testers, a master set of programmable integrated circuits, and a program development system were included as deliverables.

The contract was awarded to the Space Information Systems Operation (SISO) of Ford Aerospace & Communications Corporation (FACC) on 24 August 1978, as a fixed-price competitive procurement. Final system delivery was made on 22 December 1980, with the final spares shipment occurring on 22 May 1981. The original contract price was \$3,150,032. Modifications during the contract increased the price to \$3,272,677. Actual cost of the project will be between \$4.8 million and \$4.9 million depending on the level of success in dispositioning surplus material. A claim for extraordinary cost relief was submitted by SISO in June 1980. The claim requests government relief for less than 20 percent of the loss absorbed, and is for that portion clearly beyond the control of SISO.

Status of the systems is that all three MDM's have been installed, and have been operationally tested. Significant use of the GSFC/TDRSS links has occurred since its initial installation and test. Use of the JSC system has been minimal to date. The systems have performed well with no major problems. The remaining text in this report summarizes the progress and problems analysis, addresses schedule conformance, new technology, items awaiting government approval, and project conclusions. In addition, the appendix lists all contract modifications with a brief description of each.

SECTION 2

PROGRESS AND PROBLEMS ANALYSIS

2.1 GENERAL

This section of the report summarizes both project progress and problems in chronological order. The project made numerous accomplishments and had problems that are not mentioned herein for the sake of brevity, but those cited are considered significant in understanding the total workflow. The events reported in this document are referenced to the type 1 monthly progress reports by paragraph title.

2.2 ANALYSIS OF PROGRESS AND PROBLEMS

2.2.1 August 1978. The contract was awarded to SISO on 24 August 1978, after a firm fixed-price competitive procurement cycle. Staffing began immediately, but no progress report was submitted for August.

2.2.2 September 1978. The Preliminary Design Review (PDR) was conducted at SISO's facility in Houston, Texas, from 19 August through 21 September. No major requirements or design changes occurred, although multiple action items were assigned to clarify system details. SISO submitted the following plans as contractually required:

- QA Inspection
- New Technology Reporting
- Affirmative Action
- Small Business Subcontracting
- Minority Business Enterprise Progress
- Reliability Program.

An Engineering Change Proposal (ECP) was also submitted to GSFC per their request for power consumption reduction.

2.2.3 October 1978. All PDR action items that affected progress were resolved. Authority to proceed in implementing the power consumption reduction ECP was granted. Logic design started and procurement began on parts needed to checkout circuitry being prototyped.

2.2.4 November 1978. The Interim Design Review (IDR) was conducted from 15 through 17 November in Houston. No problems of any consequence surfaced, but considerable time was expended discussing the addition of software and operational features to the control subsystem. Procurement of long-lead material items began.

2.2.5 December 1978. Per GSFC request, SISO submitted a proposal for multiple software enhancements and improved operational features in the control subsystem. Prototype checkout of logic was in process.

2.2.6 January 1979. Sheet-metal fabrication started on SISO standard hardware, and procurement activity accelerated as the overall logic design became more complete. Artwork development was in process for the patch and switching printed circuit boards (PCB's). GSFC notified SISO that control subsystem terminals and printers were to be Government-Furnished Equipment (GFE), and SISO responded with an assessment of impact and a proposal for credit to the contract.

2.2.7 February 1979. Negotiations were completed for the purchase of some of the additional software and operational features proposed by SISO in December 1978. The contract additions were accompanied by a schedule extension. Logic design was now at a peak with Input Terminal Unit (ITU) and Output Terminal Unit (OTU) wired prototypes in checkout. Programmable test fixtures were used to simulate other system components.

2.2.8 March 1979. The Critical Design Review (CDR) was conducted at Houston from 5 through 7 March. The software design phase was completed and coding began for the control subsystem software. Manufacturing effort on racks and subassemblies started. Problems with the delivery of some parts forced workarounds in prototype checkout, thus limiting progress.

2.2.9 April 1979. Checkout of the wired-prototype ITU's and OTU's was completed, and artwork development packages were delivered to the vendor. Logic design was completed and released for wirelisting on the input and output controllers. The first microcomputer chassis was completed and checkout began, but was delayed three weeks due to the late installation of the teletype (GFE) equipment. A two-week schedule extension was agreed to based on this problem.

An in-house cost review during April indicated that a significant cost overrun in the material area was probable. Material costs due to changed market conditions was causing excessive prices to be paid for items relative to their proposed cost. In addition, the items actually used in the design were in some cases considerably more expensive than their counterparts that were priced in the proposal. An in-house analysis to determine what created the material cost problem, and to scope the problem was initiated.

2.2.10 May 1979. The schedule became jeopardized as parts deliveries paced manufacturing. The ITU design was being refined which limited artwork development. The artwork vendor was slipping promised deliveries. Firmware design was completed for the input and output controllers.

2.2.11 June 1979. Firmware coding was completed for the input and output controllers. Checkout of the first set of printed wiring boards (PWB's) for the input and output controllers began. Availability of integrated circuits limited the checkout effort considerably. The tight market for integrated circuits caused SISO to reorder many integrated circuits during this time frame in an attempt to acquire enough components to support checkout. These parts were ordered at spot-market prices, but with a better chance of delivery than on longstanding orders at lower prices. The alternative was to delay the project and wait for vendor deliveries.

2.2.12 July 1979. Software checkout utilizing the development system and microcomputer chassis progressed well. Applications software was basically integrated with the operating system.

2.2.13 August 1979. Replaceable parts lists and spare parts lists were completed and delivered. All artwork development was completed and initial quantities of all PCB's were ordered.

2.2.14 September 1979. SISO prepared and submitted TP9275 for cost and schedule impact for manuals compliant with GSFC 256-4. The equipment delivery schedule was reported as no longer being attainable due to many parts shortages. Items short at that time included: (1) integrated circuits, (2) power supplies, (3) PCB bus bars, (4) PCB's, (5) hardware for mounting ITU/OTU panels, (6) patch panels, and (7) miscellaneous sheet metal subcontracted out of SISO. Checkout was now a major activity even with parts shortages. The OTU frequency synthesizer layout on the PCB was determined to be highly sensitive requiring an artwork revision. Manufacturing completed assembly of one each of the rack types minus the parts shortages.

2.2.15 October 1979. SISO requested a schedule extension to April 1980, for equipment delivery based on material problems. An internal review revealed that the total loss on the contract would be significantly higher than predicted earlier. This was based on a continuing material price problem and labor overruns now projected based on schedule slips. Checkout of the preproduction PCB's was completed and five of the PCB's required minor artwork revisions.

2.2.16 November 1979. Reliability analysis for the MDM Control Subsystem was submitted to GSFC. String testing of the first JSC multiplexer and demultiplexer began.

2.2.17 December 1979. Reliability analysis for the total MDM hardware configuration was completed and submitted to GSFC. The data confirmed that the MDM design theoretically met the specified failure rates. Manufacturing continued to produce subassemblies and racks; 29 out of 59 racks were manufactured and ready for QA and testing.

2.2.18 January 1980. The Equipment Qualification Test (FQT) procedure was completed and submitted to GSFC for review. The software standalone debug was complete except for one module, and hardware/software integration began. PCB production was in process with approximately 800 PCB's manufactured. Delivery of parts for PCB's was still a problem that limited board inspection. Problems with the output controller design were pacing the string-level checkout.

2.2.19 February 1980. A problem surfaced in early February that essentially halted PCB production. The inspection criteria for solder flow on the top side of the board could not be reasonably met, and excessive handwork was required to make a PCB acceptable. After a reliability analysis, the problem was resolved by relaxing the standard and requesting GSFC approval of the QA standards change. This request was accepted later by GSFC with SISO offering a three-year warranty on all solder connections affected by this relaxed standard. The Acceptance Test (AT) procedure was completed and submitted to GSFC for review and approval. Manufacturing had now completed 44 of the 59 racks and was progressing well. The final twinax cable that had previously threatened to halt progress had been received. Another bright spot was that for the first time data was run at 10 megabits per second through a string of equipment in preliminary testing. A rescheduling effort started as the April equipment delivery appeared to be impossible due to many problems which included: (1) impact of late parts delivery, (2) remaining parts shortages, (3) output controller design problems which required excessive changes in checkout, (4) past PCB production problems, and (5) estimated problems remaining in system that checkout had not yet exposed.

2.2.20 March 1980. SISO finally received the final quantities of PCB's and integrated circuits to complete production. One schedule plan was submitted to GSFC for review and alternative plans were studied by both GSFC and SISO.

2.2.21 April 1980. The preliminary operations and maintenance (O&M) manual was submitted by SISO for review by GSFC. The rack assembly effort was completed and PCB production was now 84 percent complete. Output controller design problems continued to pace system level checkout; however, the system operated error free for hours at times, if allowed to run without interference. Apparent minor, but intermittent, problems persisted that usually showed up as a Triple Modular Redundant (TMR) error. The schedule continued to be studied and negotiated.

2.2.22 May 1980. String-level tests continued with all elements of the system now integrated, but minor intermittent problems remained. Electromagnetic compatibility (EMC) tests were performed by a subcontractor on the JSC string 1 equipment. The PCB assembly effort was completed except for a few boards in QA rework. The schedule was still under consideration by SISO and GSFC.

2.2.23 June 1980. The schedule was negotiated with consideration to the government for a 22 December 1980, on-dock delivery of the MDM equipment at all three geographical sites. SISO submitted a claim for extraordinary costs relief in an attempt to recover a part of the contract loss.

2.2.24 July 1980. SISO received review comments from GSFC on the Equipment Qualification Test Procedure (EQTP), Acceptance Test Procedure (ATP), and the preliminary O&M manual. SISO conducted an internal design review and analysis utilizing non-project related senior technical personnel from SISO and FACC, Western Development Laboratories Division. No significant changes resulted from the review, but several suggestions were followed that aided in the isolation of remaining problems. System checkout continued with three significant events: (1) implementation of the dispatch algorithm proved to limit the useful bandwidth of the multiplexer; (2) a tracking logic problem was discovered in the OTU; and (3) all 74LS279 logic was replaced with 74279 logic which resulted in a more stable system (fewer intermittent problems).

2.2.25 August 1980. Design problems in the dispatch algorithm and tracking logic were resolved and the EQT was dry-run. Minor problems surfaced, were resolved, and the EQT was repeated a second time. Only software/firmware interface problems of a minimal nature remained. All output controller PWB's were completed by Manufacturing that were rewired to include all design changes. SISO submitted the test data from the EMC testing conducted in June, along with an analysis and recommendation for acceptance of the test data and equipment. The data indicated that the MDM surpassed all susceptibility requirements, but exceeded emissions specification at a few frequencies. SISO's recommendation was later accepted by GSFC after their investigation of the three sites actual environments.

2.2.26 September 1980. SISO proposed and received approval to implement a change in the OTU tracking logic that not only resolved the problem discovered in July, but improved the tracking range to the degree the specification could be improved. This change for improved performance was implemented for consideration to SISO. Checkout and integration of the JSC and GSFC string number 1 equipment was completed and the racks were submitted to QA for final inspection.

2.2.27 October 1980. Integration of all hardware and software continued except on those systems already completed. Functional testing of spares started. Final inspection of the racks continued and rework was performed as required. At the end of October, 27 racks were inspected and sealed.

2.2.28 November 1980. The functional testing of all operational and site spare PWB's was completed and depot spares checkout started. Multi-string testing of the control subsystem software was completed. QA had completed final inspection on 48 of the 59 racks at the end of November.

2.2.29 December 1980. Final inspection was completed on all racks, operational spares, site spares, and all but 30 output controller depot spares. The EQT was successfully completed. The AT was successfully completed on all of the equipment listed above. The equipment was packaged and shipped arriving at GSFC and the TDRSS ground terminal on 18 December, and at JSC on 22 December.

2.2.30 January 1981. A one-week training course was conducted at GSFC on the MDM system for personnel from each of the three sites.

2.2.31 February 1981. The final O&M manuals were shipped to GSFC along with a reproducible set of manufacturing drawings.

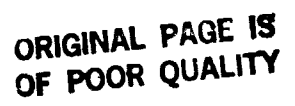
2.2.32 May 1981. The final shipment including depot spares and site-piece part spares (shortages in previous shipment) was sent to GSFC.

SECTION 3

SCHEDULE CONFORMANCE

The initial equipment (systems) on-dock delivery date stated in the contract was 10 December 1979. This was revised to 11 February 1980 via add-ons and because of problems with GFE. Several slips beyond 11 February 1980, were discussed and proposed based on incremental deliveries to the three geographical sites. One schedule slip was agreed to and negotiated with consideration to GSFC. Negotiations concluded in June 1980, called for a simultaneous delivery to all three sites on 22 December 1980. This schedule was improved upon slightly as the actual on-dock delivery dates at GSFC and White Sands were 18 December 1980, and the on-dock delivery date at JSC was 22 December 1980.

The contract schedule from award to systems delivery was approximately 28 months. The slip was from 11 February to 18/22 December, or approximately 10½ months. The slip accounts for slightly more than one-third of the total schedule. The three primary causes of the slip in descending order of schedule impact were: (1) material delivery delays aggravated by the market condition for integrated circuits; (2) a success-oriented initial schedule which was highly optimistic considering the complexity of TMR, 10 MHz logic development; and (3) excessive redesign of the multiplexer output controller logic requiring a percentage change in checkout that was exceptionally high for SISO, even considering the complexity. Refer to figure 1 for the completed summary level schedule for the project.



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SECTION 4

NEW TECHNOLOGY

The MDM utilized state-of-the-art existing off-the-shelf components and design techniques only. The logic configurations and speeds do far exceed commercially available equipment of a similar nature, but do not constitute a new technology.

SECTION 5

ITEMS AWAITING GOVERNMENT APPROVAL

There are no open items on the contract awaiting approval by the government except the SISO claim for Extraordinary Contract Adjustment. This claim is for less than 20 percent of the loss absorbed by SISO and amounts to approximately \$288,000. The claim was originally submitted 26 June 1980, and additional supporting data was submitted by GSFC request on 5 November 1980.

SECTION 6

PROJECT CONCLUSIONS

The development of the MDM Data Systems was a significant technical achievement. The NASA requirements in the TDRSS era of the Space Shuttle program make this development necessary. The systems are unique in the current world of electronics and communications. The primary features that distinguish the MDM are its reliability (10,000 hours Mean-Time-Between Failures (MTBF), data rate capabilities (up to 7 megabits per channel and 10 megabits aggregate rate), and format versatility (NASCOM-blocked data or serial bit contiguous data). The systems incorporate TMR logic in the critical areas of the multiplexers and demultiplexers where data from more than one input/output (I/O) channel is operated on. The TMR system architecture was required to achieve the specified reliability. The systems have been installed and have been operating satisfactorily for about four months at this time.

In summary, SISO was pleased to be chosen to participate in the Shuttle program as a GSFC contractor to develop the MDM Data Systems. We believe that a quality product has been delivered that will serve NASA's needs for many years. The project implementation was not simple or smooth throughout, but SISO's technical skills and project commitment were certainly demonstrated. The one schedule slip was significant, but the systems have been delivered to NASA allowing sufficient time for their evaluation and testing. Other TDRSS systems have slipped to the extent that the late MDM delivery did not impact NASA's operation. The project, from the contractor's viewpoint, has to be considered highly successful in all aspects except for the absorbed financial loss. An opportunity to reduce the loss exists in the claim for extraordinary cost relief that remains open, and in the sale of additional MDM systems. A development project of this magnitude and complexity should possibly have been a type of cost-plus contract to share the risk between the contractor and government.

APPENDIX

NAS 5-25093 CONTRACT HISTORY

FACC, through SISO, contracted with the NASA GSFC to provide NASCOM, TDRSS Shuttle MDM Data Systems and supporting items under Contract NAS 5-25093. The contract award date was 24 August 1978, and incorporated NASA/GSFC Specification 841-77-03, Revision 6, dated May 1978.

The following modifications were made to this contract.

1. Modification 1, 24 August 1978. The purpose of this contract modification was to add a new article, (Article XXXI, Applicability of Rights in Data Clause), increase the funds allotted pursuant to Clause 242 (Limitation of Government's Obligation), and to revise several contract articles. As a result, the following articles were revised:
 - o Article III, Place of Performance
 - o Article VI, Shipping Instructions
 - o Article XXV, Incorporation of Contract Clauses by Reference
 - o Article XXVI, Contents of Contract
 - o Article IV, Limitation of Government's Obligation.
2. Modification 2, 6 September 1978. The purpose of this contract modification was to increase the funds allotted pursuant to Clause 242.
3. Modification 3, 22 November 1978. This modification included the following changes.
 - a. Contract Specification, S-841-77-03, Revision 6, was changed in accordance with Revision 7, dated 25 October 1978.
 - b. The quality assurance provisions of Article XIV, Quality Assurance, were revised to add the following stipulation: adjustable wire strippers (i.e., Miller type) will not be used in the fabrication of equipment covered by this contract.
 - c. The fixed price of this contract and the funds allotted for the performance thereof, shall not be increased or deemed to be increased by this change order. Any claim for an increase in the fixed price of this contract must be asserted in accordance with the terms of the changes clause of this contract. Until a contract modification is made, as a result of such assertion, the contractor is not obligated to continue performance or increase costs beyond the point established in Article IV of this contract.
4. Modification 4, 15 November 1978. The purpose of this contract modification was to increase the funds allotted pursuant to Clause 242.

5. Modification 5, 28 February 1979. This supplemental agreement constituted complete and equitable adjustments for the following changes.
 - a. Change Order Modification 3, Revision 7, to Contract Specification 841-77-03, TWX change dated 11 January 1979, covering Revision 8 to the contract specification, and in TWX change dated 22 January 1979, covering Revision 9 to the contract specification.
 - b. FACC Engineering Change Proposal TP9246 dated 5 December 1978.
 - c. TWX authorization dated 22 January 1979, to substitute refurbished teletype unit, model ASR 33, in lieu of new unit.
 - d. GSFC letter file 2780 dated 1 December 1978, approving the use of FACC's SISO Standard Manual, Vol. 2, dated 3 October 1977, conditioned on incorporation of GSFC revisions as cited in revised Article XIV, Quality Assurance of this modification.
 - e. Extensions to item 9, Article I, Design Review Meeting, contained in revised Article XVII, Design Review Presentation.
6. Modification 6, 11 October 1979. The purpose of this contract modification was to amend the contract delivery schedule, adjust the contract price, add government-furnished property, and add a new deliverable item. This modification specifically incorporated NASA/GSFC Specification S-841-77-03, Revision 10, dated 29 August 1979.
7. Modification 7, 23 April 1980. The purpose of this supplemental agreement was to increase the fixed price of this contract to reflect an agreement reached on the upgrading of technical manuals and to provide funds for the repair of government equipment.
8. Modification 8, 10 June 1980. The purpose of this supplemental agreement was to add a schedule article to implement a PCB warranty.
9. Modification 9, 24 June 1980. The purpose of this supplemental agreement was to extend the delivery schedule, realign the spare part delivery, and add two new deliverable items. These modifications were effected at no additional cost to the government.
10. Modification 10, 26 September 1980. The purpose of this supplemental agreement was to renumber the Government Property Article and add item 2, Government Property Furnished to the article. In addition, the Technical Officer and Contract Specialist were changed.
11. Modification 11, 15 December 1980. The purpose of this supplemental agreement was to incorporate NASA/GSFC Specification S-841-77-03, Revision 11, dated ~ October 1980, at no cost to the government.
12. Modification 12, 5 January 1981. The purpose of this supplemental agreement was to change the OTU timing requirements and provide equitable adjustments. Also, the government will provide an additional data block emulator under Article XXXIII, Government Furnished Property.